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Combined Geoelectrical and Statistical Approach in Subsurface Structural Mapping for Groundwater Prospect at Oke-Odo, Iwo, Southwestern Nigeria

A. A. Adeniji[1, 2], T. A. Adagunodo[3*], O. O. Ajani[1, 2], T. K. Samson[4], M. R. Usikalu[3], C. A. Onumejor[3]

Department of Physics and Solar Energy, Bowen University, Iwo, Nigeria[1]
Space and Geoscience Research Observatory, Bowen University[2]
Department of Physics, Covenant University, Ota, Nigeria[3*]
Department of Mathematics and Statistics, Bowen University, Iwo, Nigeria[4]

ABSTRACT— This research is aimed at mapping the subsurface structures such as fracture, weathered basement and fresh basement for groundwater investigation at Oke-Odo, Iwo, Osun State, Nigeria using combined geoelectric and statistical approach. Six (6) vertical electrical resistivity sounding data are collected based on schlumberger electrode arrangement configuration and maximum current electrode spacing of AB/2 along 100 m within the study area. The vertical electrical sounding (VES) results presented as resist graph revealed the range of values for all the VES stations respectively. The depth ranges from (0.9 – 37.5 m), thickness ranges from (0.9 – 35.1 m) and resistivity ranges from (27.3 – 3353.4 ohms). These results were later used to generate 2-D geoelectrical maps of the subsurface study area, which revealed that the fractured-weathered basement varied, leading to diversity in groundwater prospects. A descriptive statistic was computed for resistivity, thickness and depths values respectively from the resist graph. The normality of the data was examined using the Shapiro-Wilk's test while test of homogeneity of variance was carried out using the Levene's test. Resistivity between layers were compared using the ANOVA followed by Duncan's test for Post Hoc comparison while thickness and depth between layers were compared using the independent t-test. The modeled geoelectric and statistical approach on the groundwater potential revealed that groundwater yield was recorded in areas with large concentrations of fracture and weathering with the bedrock.

KEYWORDS: Groundwater exploration, Vertical electrical sounding, Statistical approach, Analysis of Variance (ANOVA), Precambrian Basement.

1. INTRODUCTION

The important of subsurface structural mapping for groundwater investigation is very crucial because its potential availability is one of the major factors that promote a healthy and favorable living for humans around the globe. [51] reported that the occurrence of groundwater is based on the geologic subsurface formation which is influenced by fluid force in the pores, fracture or cracks of rocks. The potential of groundwater deposit may be located within the sedimentary formation where its exploit can be less difficult to achieve or also located at basement complex terrain under the crystalline un-weathered or unfractured rocks where exploit can be difficult to manage. [11] reported that the insufficient adequate of surfacewater allows the world to condition and rely on the largest availability sources of fresh quality water that is beneath the subsurface and this is known as the groundwater, which is refers to the fluid/water held within the subsurface in saturated zones under hydrostatic pressure below the aquifer. [5] reported that the consumption of groundwater as more advantages as a source of potable quality water for humans with little or no purification is needed, as it is generally unconstrained from chemical and biological contaminant. [50] reported that the important of groundwater for human uses is huge and prevalence but revealed the inadequate provisions to a great extent within the basement complex formation since majority of the boreholes are either imperfectly construct or cannot recompense sustainable production of water resource to well. Furthermore, the occurrence of groundwater exploration and exploitation particularly in Precambrian basement complex, are influenced and controlled by different factors as reported by [28] and [9], such as lithology, topography and structures like fractures zones, faults zones and nature of weathering pattern. In addition, [26], [12] and [10] support that oftentimes; groundwater occurrence is limited and restricted principally to weathered/fractured zones in the basement terrain. [40] reported that esteem groundwater release is said to be associated with hard rock terrains where composite aquifer is found beneath the fractured/ weathered basement. Consequently, the problem of acquiring adequate quality groundwater resource for consumption supply has gradually become more demanding because of the rapid increase with population and industrial activities within the study area, in this regards, the dependability of surfacewater during the year is repudiating and disaffirming. Therefore, [35] and [39] placed emphasizes on vertical electrical resistivity sounding has a method in surface geophysical survey to locate and identify the primary aquifer zones before boreholes is been made. [7] reported that electrical resistivity application has been vastly adopted to explore groundwater among diverse methods of geophysical applications. [52] also reported that subsurface investigation employing vertical electrical resistivity sounding provide very rapid, quick and cost effective means of retrieving established details of subsurface geological information. [6] affirmed that volumetric measurements and subsurface images can be revealed by geophysical method without physically disturbing the subsoil. The important and relevant of using electrical resistivity method in exploring groundwater has been explicated by different researchers such as [44], [46], [41], [31], [13], [29], [33], [48], [50], and [51].

A statistical analysis was perform using the SPSS version 20.0 [30] and Graphpad Prism 5.0 [20]. This was done to examine the normality of the data as reported by [45], test of homogeneity of variance, [25], determine Duncan's test for Post Hoc comparison, [18] and carry out an independent t-test for the subsurface structural parameters [42]. Thus, the present research utilized the VERS techniques to subsurface structural investigation and the possibly locations for groundwater prospects, using a strong procedure on foundation of three geoelectric parameters, such as: bedrock depth, bedrock thickness and bedrock resistivity which are obtained from the resistivity sounding inversion data. The three geoelectric parameters were later subjected to a descriptive statistics based on the normality of the data, test of homogeneity of variance and comparison of geoelectric parameters. The study area is located within coordinate latitude 7°50°to 8°00' N and longitude 4°00' to 5°00' E, at Oke-Odo, Iwo southwestern Nigeria as shown from (Fig. 1). It is in the Precambrian basement complex [43] comprising predominantly migmatized and undifferentiated gneisses, schist, older-granite, dolorite, dykes, charnockitic rocks and quartzite of Precambrian age [22, 49].

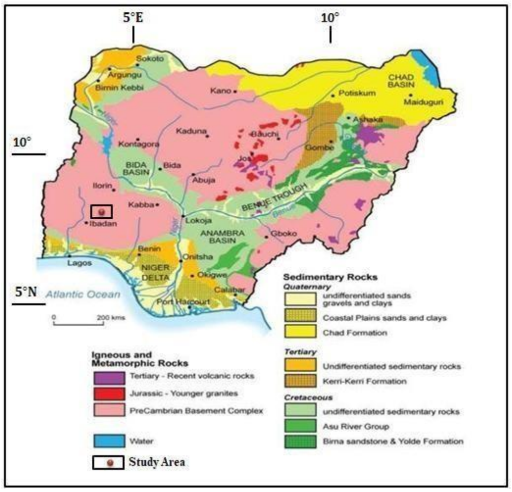


Figure 1: Geological map of Nigeria, indicating the location of the study area [27].

There texture is fine and also have varying colour which ranges from white clay brown to fairly brownish yellow and brownish red [8]. Its average thickness is 50 mm and overlies the western upland region of the Nigeria highland plateaux which has an altitudinal mean ranging between 1000 m and 1500 m above average sea level [8]. Locally, the observed tropical rainfall event in Iwo is which that govern majority of southwestern part of Nigeria. Two major distinctive seasons such as raining and dry season are observed within the study area. The occurrence of the raining season is mostly often between March and October, while the dry season is observed around November and February annually. The study area annual rainfall is about 1247 mm, but varies between 1016 mm to 1524 mm.

2. Materials and Methods

The electrical resistivity method employing the Schlumberger electrode array configuration was used to execute the geophysical survey [54, 14]. This is shown from Fig. 2.

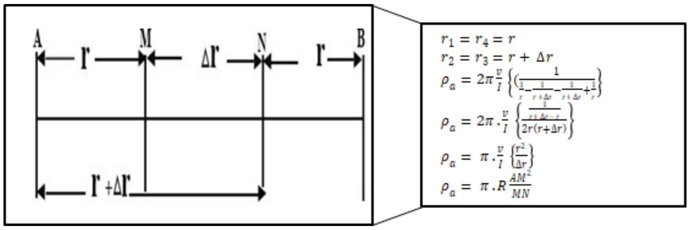


Fig. 2: Schlumberger electrode configuration (modified by [14])

The basic for electrical resistivity theory as reported by [19], is Ohm's law. The law is related to voltage, resistance and current and state that the current (I) that passes along a metallic conductor is proportionately in constant ratio to the potential difference (P.d) with the condition that all physical quantities remain constant. This impliesV α I.Where V indicate the P.d in volts (V); I = current in ampere (A). When a known resistance is applied we have that V = IR. Therefore, R is the constant known as resistance in ohms (Ω). The resistivity of the subsurface can be determined due to the inhomogeneous nature of the ground. But if the subsurface resistivity is uniformly distributed, the measure value of the resistivity will be unchanged and constant independently of the electrode spread and surface locations. However, since the subsurface has varying resistivity, the measured resistivity is called the apparent resistivity (ρa) which depends on subsurface layers, size and shape of the anomalous zones, and relative values of resistivities in these zones. The apparent resistivity (ρa) can be enumerate by ρa = k(V/I), position K stand for the geometric factor which is which based on the pattern of the electrode spacing. Also, since the resistance R = V/I, which is what is revealed in regards to the resistivity meter or Terameter. The apparent resistivity can be calculated as ρa = KR. Six (6) VES stations were occupied along north-west direction as shown in the base map Fig. 3. The Ohmega digital resistivity metre was applied for the purpose of data acquisitions. The electrical method was established with current electrode spacing of maximum half width (AB/2) varying between 65 m to 100 m which depends on the spread allowance and depth extent to basement. This was performing by varying the separation among the current electrodes, to allow the current penetrates the subsurface which varies with respect to depth range [52]. The geoelectrical sounding data was interpreted automatedly based on the theoretical and auxiliary curves [23, 24], which were curve matched in determining the values of resistivity,corresponding thickness and depth value between diverse and separate subsurface zones [2, 4, 16, 21]. The geoelectrical parameters obtained were further subjected to forward modeling computer based algorithm using WinResist software version 1.0 [53]. This was done so as to have output with low root mean square (RMS) values.

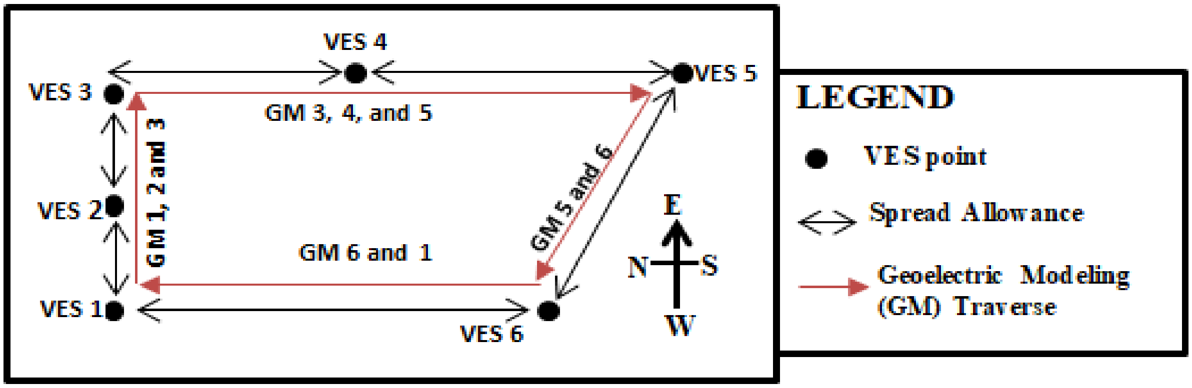
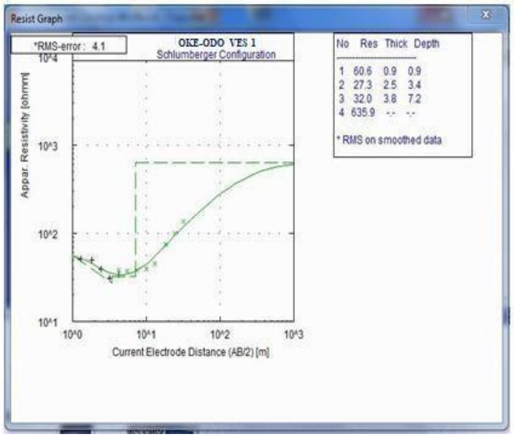


Fig. 3: Base map showing the VES located from the study area

Descriptive statistics was computed for resistivity, thickness and depths. The normality of the data was examined using the Shapiro-Wilk's test. [45] reported that testing for normality in particular has been a major area of continuing statistical research both theoretical and practical. He revealed that the possible cause of this interest is that many statistical procedures have been derived based on particular distribution assumptions, especially that of normality. The test for homogeneity of variance was carried out using the Levene's test. [25] presented a test for homogeneity (equal variance) and reported that the test is an inferential statistic used to determine the equivalence of variables. Comparison between resistivity layers was done using the Analysis of Variance (ANOVA) as reported by [47], followed by Duncan's test for Post Hoc comparison [18] while thickness and depth between Layers were compared using the independent t-test [42]. Result is also presented graphical using cluster bar chart to show the level of resistivity, thickness and depth for each VES stations in each layer. The Statistical Package for Social Sciences (SPSS version 20.0) and Graphpad Prism 5.0 were used to analyse data and statistical significance was established at the 0.05 level of significance with p<0.05 signifying significant result.

3. Results and Discussion

3.1 Results for VES



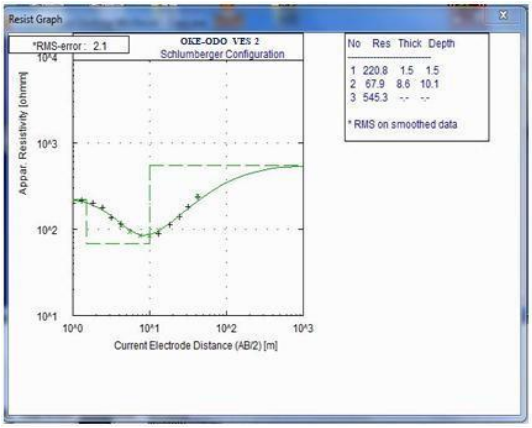
*RMS-error : 4.1

OKE-ODO VES 1
Schlumberger Configuration

No	Res	Thick	Depth
1	60.6	0.9	0.9
2	27.3	2.5	3.4
3	32.0	3.8	7.2
4	635.9	-.-	-.-

* RMS on smoothed data

Fig. 4a: Modeled Resist Graph for VES 1



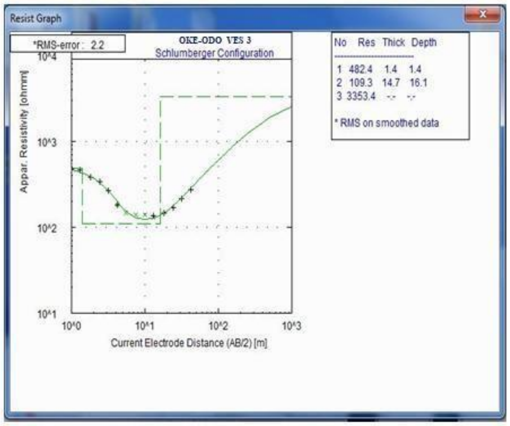
*RMS-error : 2.1

OKE-ODO VES 2
Schlumberger Configuration

No	Res	Thick	Depth
1	220.8	1.5	1.5
2	67.9	8.6	10.1
3	545.3	-.-	-.-

* RMS on smoothed data

Fig. 4b: Modeled Resist Graph for VES 2



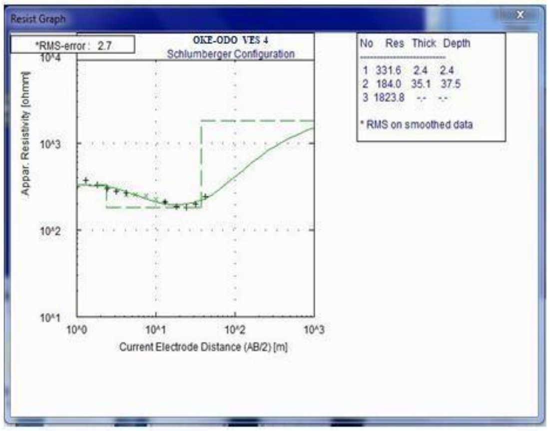
*RMS-error : 2.2

OKE-ODO VES 3
Schlumberger Configuration

No	Res	Thick	Depth
1	482.4	1.4	1.4
2	109.3	14.7	16.1
3	3353.4	-.-	-.-

* RMS on smoothed data

Fig. 4c: Modeled Resist Graph for VES 3



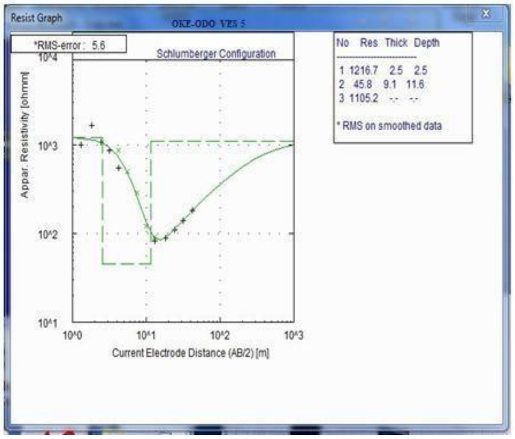
*RMS-error : 2.7

OKE-ODO VES 4
Schlumberger Configuration

No	Res	Thick	Depth
1	331.6	2.4	2.4
2	184.0	35.1	37.5
3	1823.8	-.-	-.-

* RMS on smoothed data

Fig. 4d: Modeled Resist Graph for VES 4



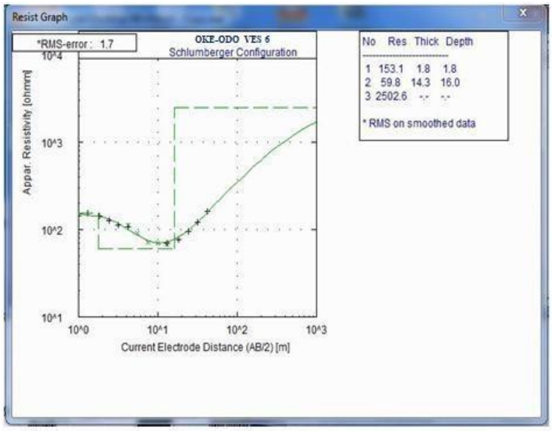
*RMS-error : 5.6

OKE-ODO VES 5
Schlumberger Configuration

No	Res	Thick	Depth
1	1216.7	2.5	2.5
2	45.8	9.1	11.6
3	1105.2	-.-	-.-

* RMS on smoothed data

Fig. 4e: Modeled Resist Graph for VES 5



*RMS-error : 1.7

OKE-ODO VES 6
Schlumberger Configuration

No	Res	Thick	Depth
1	153.1	1.8	1.8
2	59.8	14.3	16.0
3	2502.6	-.-	-.-

* RMS on smoothed data

Fig. 4f: Modeled Resist Graph for VES 6

3.2 Discussion of VES Results

The data results obtained from the study were presented in form of resist graph, table, and geoelectric layers. It was observed from the modeled resist graph that most of the curves show three layers except in station one, where we have four layers (Figure 4a-f). The field curves observed was classified as H–types respectively and the summary of the resist graph are presented in Table 1. From the resist graph, the depth to basement of VES 1, 2 and 5 are not up to 15 m. The result shows that these areas have thin overburden thickness. Therefore, it is considered to be very poor for groundwater investigation even though VES 2 has a fractured basement. Also, VES 3, 4 and 6 shows thick overburden thickness (depth to basement greater than 15m) [48] and [1] but the basement at these regions are fresh basement, which is also considered to be very poor for groundwater. In regards to this, [40] reported that the best zones to give the highest quality groundwater yield is the weathered/fractured basement with thick overburden. The observed feature in VES 5 layered 1 with resistivity of 1216.7 Ωm shows the presence of a laterite as reported by [51]. ―Laterites are weathered material composed principally of the oxides of iron, aluminum, titanium, and manganese. Laterite ranges from soft, earthy, porous soil to hard dense rock‖.

Table 1: showing the detailed quantitative summary of resistivity, thickness and depth of VES points

VSt	**LA**	**RES (Ωm)**	**TKs(m)**	**DTh(m)**	**LUs**

VES 1	1	60.6	0.9	0.9	Topsoil
	2	27.3	2.5	3.4	Weathered zones
	3	32.0	3.8	7.2	Weathered zones
	4	635.9			Fractured basement
VES 2	1	220.8	1.5	1.5	Topsoil
	2	67.9	8.6	10.1	Weathered zones
	3	545.3			Fractured basement
VES 3	1	482.4	1.4	1.4	Topsoil
	2	109.3	14.7	16.1	Alluvium
	3	3353.4			Fresh basement
VES 4	1	331.6	2.4	2.4	Topsoil
	2	184.0	35.1	37.5	Alluvium
	3	1823.8			Fresh basement
VES 5	1	1216.7	2.5	2.5	Lateritic/topsoil
	2	45.8	9.1	11.6	Weathered zones
	3	1105.2			Fresh basement
VES 6	1	153.1	1.8	1.8	Topsoil
	2	59.8	14.3	16.0	Weathered zones
	3	2502.6			Fresh basement

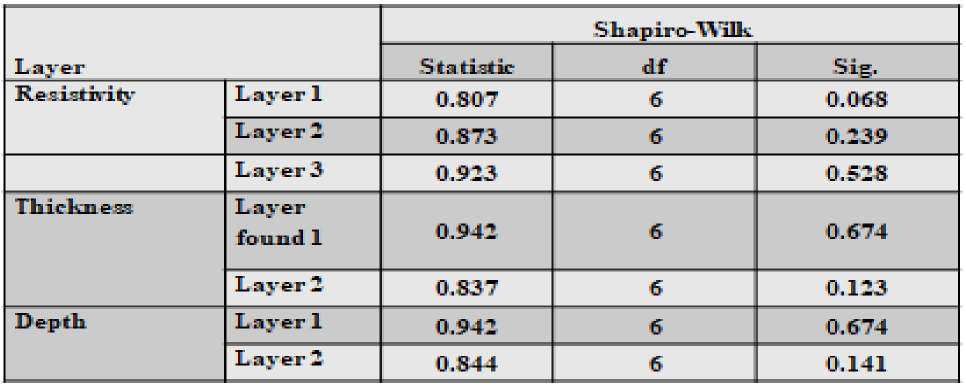
Note: VSt = VES Station

RES = Resistivity TKs = Thickness DTh = Depth

LUs = Lithology Units

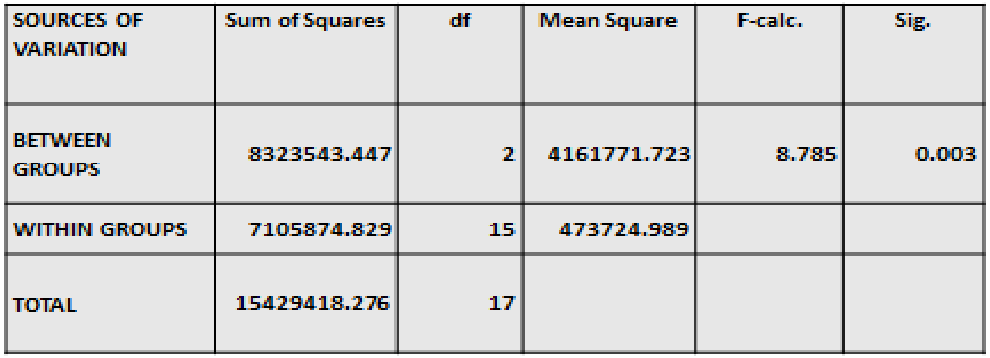
3.3 Statistical Modeling Results

Table 2: Summary result of Normality Using Shapiro- Wilk's test



		Shapiro-Wilk		
Layer		Statistic	df	Sig.
Resistivity	Layer 1	0.807	6	0.068
	Layer 2	0.873	6	0.239
	Layer 3	0.923	6	0.528
Thickness	Layer found 1	0.942	6	0.674
	Layer 2	0.837	6	0.123
Depth	Layer 1	0.942	6	0.674
	Layer 2	0.844	6	0.141

Table 3: ANOVA result summary showing differences in resistivity between layers



SOURCES OF VARIATION	Sum of Squares	df	Mean Square	F-calc.	Sig.
BETWEEN GROUPS	8323543.447	2	4161771.723	8.785	0.003
WITHIN GROUPS	7105874.829	15	473724.989		
TOTAL	15429418.276	17			

**significant at 1% (p<0.01)

Table 4: Result of the homogeneity of the population variance using Levene's test

Variables		Levene Statistic	df1	df2	Sig.
Resistivity	Based on Mean	4.957	1	10	0.051
	Based on Median	2.702	1	10	0.131
	Based on Median and with adjusted df	2.702	1	5.167	0.159
	Based on trimmed mean	4.283	1	10	0.065
Thickness	Based on Mean	4.445	1	10	0.061
	Based on Median	3.972	1	10	0.074
	Based on Median and with adjusted df	3.972	1	5.016	0.103
	Based on trimmed mean	4.418	1	10	0.062
Depth	Based on Mean	4.158	1	10	0.069
	Based on Median	3.866	1	10	0.078
	Based on Median and with adjusted df	3.866	1	5.015	0.106
	Based on trimmed mean	4.136	1	10	0.069

Table 5: Duncan's test for Post Hoc comparison for resistivity

		Subset for alpha = 0.05	
Layer	n	1	2
Layer 2	6	82.7417	
Layer 1	6	410.7667	
Layer 3	6		1661.0333
Sig.		.422	1.000

Mean in the same cell are not significantly different (p>0.05) while mean in different cells are significantly different (p<0.05).

Table 6: Summary of the Independent sample t-test showing differences in thickness and depth between layer 1 and Layer 2

Layer		n	Mean	Std. Deviation	Std. Error Mean	t-calc.	df	sig. (2-tailed)
Thickness	Layer 1	6	1.750	0.62	0.25	-2.73	10	0.021*
	Layer 2	6	14.16	11.10	4.53			
Depth	Layer 1	6	1.750	0.62	0.25	-3.02	10	0.013*
	Layer 2	6	15.91	11.48	4.69			

*significant at 5 % (p<0.05)

3.4 Discussion of Statistical Modeling Results

Table 2: It presents the result of the normality of the data using Shapiro-Wilk test. For resistivity, p-values of 0.068, 0.239, and 0.528 were obtained for Layer 1, 2 and 3 respectively. For thickness, the result yielded p-values of 0.674 and 0.123 for Layer 1 and 2 while for depth, p-values of 0.674 and 0.141 were obtained. Result

shows that the p-values obtained for each layer and for each of the parameter (resistivity, thickness and depth) were all greater than 0.05 ($p>0.05$). This implies that the distribution of the data obtained for resistivity, thickness and depth were all normally distributed. Therefore, the assumption of normality is satisfied.

Table 3: Result of Analysis of Variance (ANOVA) is presented in Table 3. Result shows F-calculated of 8.785 with p-value of 0.003. The probability value of 0.003 is less than 0.05 ($p<0.05$) which implies that there is a significant difference in resistivity between the layers. Table 5 presents Post Hoc test for resistivity between the layers using Duncan's test.

Table 4: Also, the assumption of the homogeneity of the variances was tested using the Levene's test and the result obtained as presented in table 4. Result of the Levene's test for the homogeneity of the population variance shows p-values greater than 0.05 which is an indication that the variances are equal. Therefore, the data satisfied both the assumptions of normality and equality of population variances, thus differences in resistivity between layers were compared using ANOVA, Independent t-test followed by Duncan's multiple range test while independent t-test was used to compare differences in thickness and depth between Layer1 and Layer 2.

Table 5: Result as presented in Table 5 shows that Layer 1 and Layer 2 are in the same group meaning that there is no significant difference in resistivity between Layer 1 and 2 ($p>0.05$) while resistivity in Layer 3 was significantly higher than that obtained in Layers 1 and 2 ($p<0.05$).

Table 6: Result of the independent sample t-test is presented in Table 6. Result reveals that thickness of Layer 2 is significantly higher than that of Layer 2 (1.750 ± 0.62 versus 14.16 ± 11.10, p-value =0.021, $p<0.05$) while for depth, it was also found to be significantly higher in Layer 1 than Layer 2 (1.750 ± 0.62 versus 15.91 ± 11.48, p-value= 0.013, $p<0.05$).

3.5 Modeled Geoelectrical and Statistical Observations

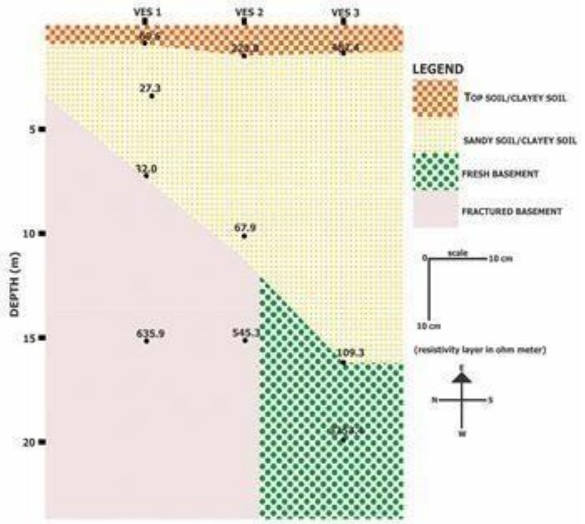


Fig. 5a Modeled Geoelectrical Observations along VES 1, 2 and 3

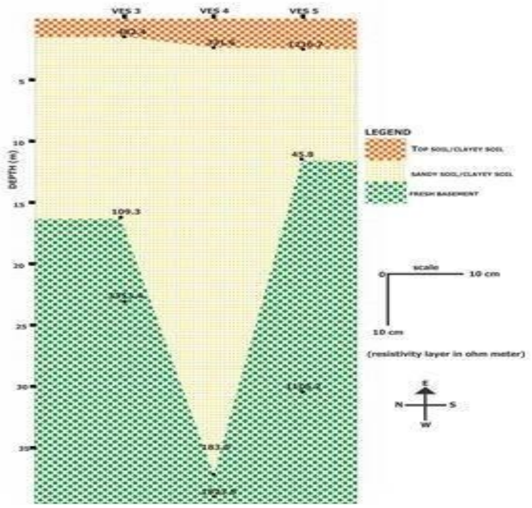


Fig. 5b: Modeled Geoelectrical Observations along VES 3, 4 and 5

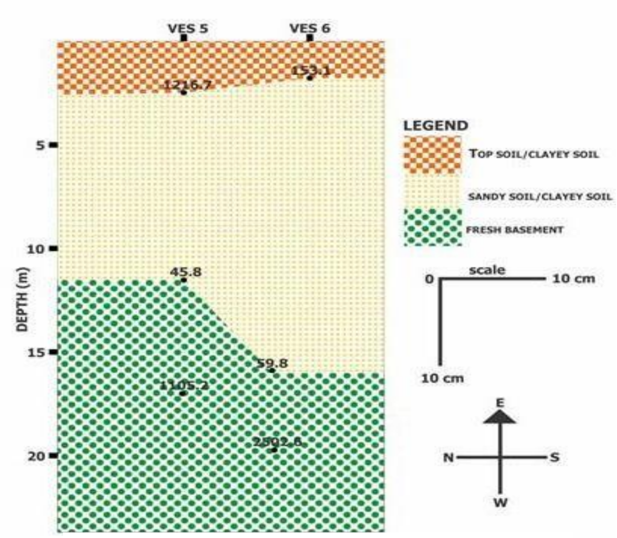


Fig. 5c: Modeled Geoelectrical Observations along VES 5 and 6

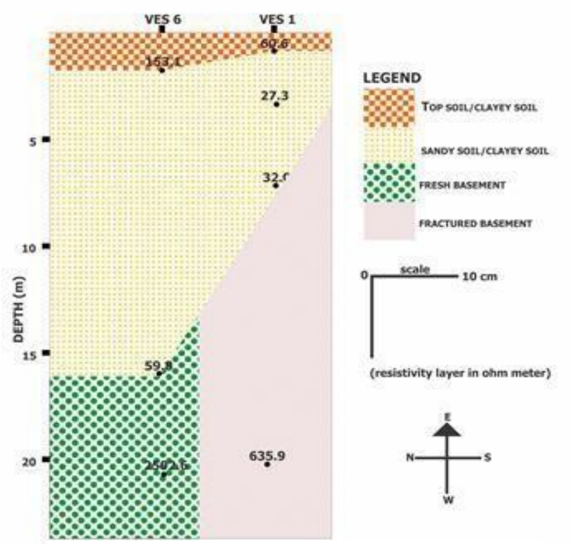


Fig. 5d: Modeled Geoelectrical Observation along VES 6 and 1

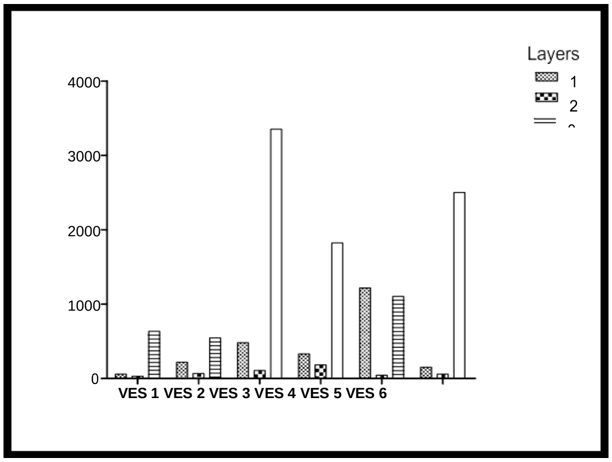


Fig. 6a: Cluster bar chart showing the level of resistivity in Layer 1, 2 and 3.

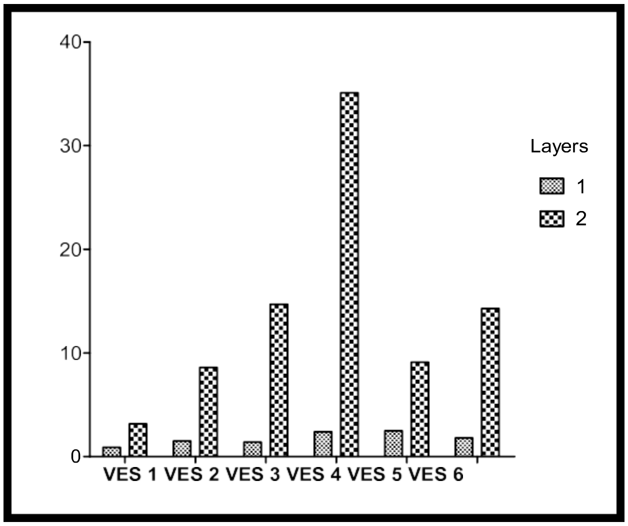


Fig. 6b: Cluster bar chart for thickness in Layer 1 and 2.

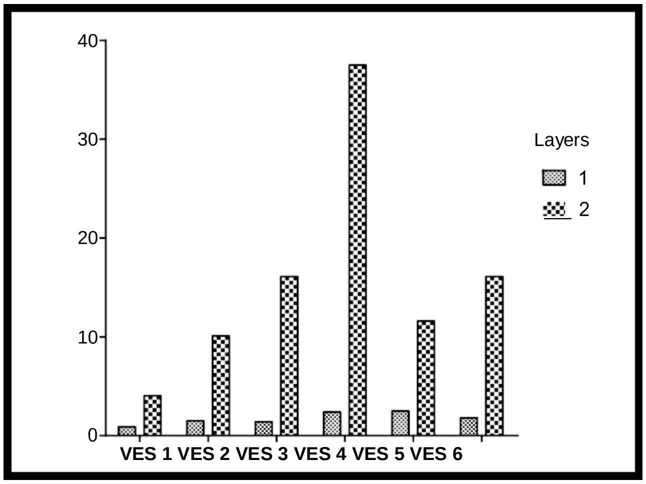


Fig. 6c: Cluster bar chart for depth in Layer 1 and 2.

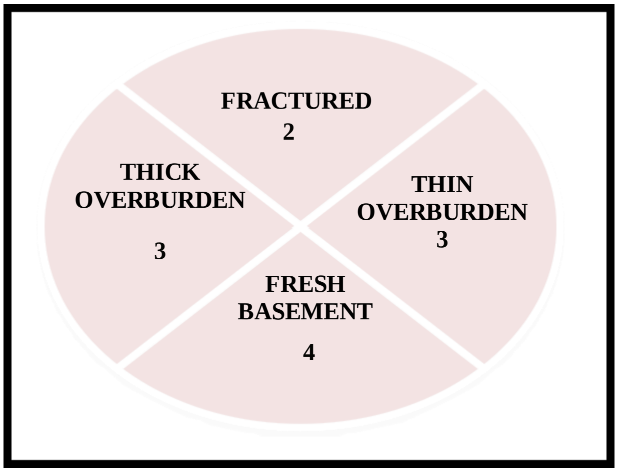


Fig. 6d: Pie Chart for the ratio between the Overburdens and the Basements

3.6 Correlations of Geoelectrical and Statistical Observations

Results of the model geoelectrical observations are presented as a 2D geoelectrical Observations. The modeled geoelectric approach unveils the existence of three to four observed geoelectrical layers as shown from Fig 5a – d. This was obtained based on how suitable and convenient they can be obtained on a straight line to see an image representation of the subsurface which unravel the vertical distribution of the resistivities. The 2D geoelectric section helps to see clearly the pseudo sections of the thin and thick overburden within the depth sounding points. The geoelectrical layer comprises of diverse geological formations such as the topsoil, lateritic, weathered zones, fractured basement and also fresh basement. The topsoil resistivity ranges between 60. 6 to 1216.7 Ωm, while the thickness ranges between 0.9 to 2.5 m and the depth ranges between 0.9 to 2.5 m. The topsoil comprises of clay, sandy clay and laterite as observed at VES 5. The second layer resistivity disclose the appearance of the weathered layer ranges between 45.8 to 184.0 Ωm, thickness ranges between 2.5 to 35.1 m and the depth ranges between 3.4 to 37.5 m. Weathered layer comprises of clay, sandy clay and alluvium as shown in VES 3 and VES 4. This layer is underlying by fracture basement as observed at VES 1 and VES 2 and fresh basement and observed at VES 3, 4, 5 and 6. The fractured basement resistivity ranges between 545.3 to 635.9 Ωm and the fresh basement ranges between 1105.2 to 3353.4 Ωm. The nature of the thin and thick overburden makes the study area less hydrogeological appealing due to the observed features at VES 1, 2 and 5 which signifies thin overburden, underlay by fractured basement and VES 3, 4 and 6 which signifies thick overburden, underlay by fresh basement. Thus the best zones recommended for exploring and exploiting sustainable quality groundwater are the zone of weather/fractured basement with thick overburden. The results of the modeled statistical observations are presented as resistivity, thickness and depth cluster bar chart as shown in Fig. 6a – c, and as overburden and basements pie chart (Figure 6d). The cluster bar chart of the resistivity (fig. 6a) shows that resistivity ranges within the subsurface. The localized diversity of the resistivity credibly characterized to the varying bedrock mineralogy and structures [32]. Groundwater prospect is an indicative of fairly low resistivity which ranges between fracture bedrock of 200 to 700 Ωm within the geoelectric bedrock. The observations of the partly low resistivity bedrock depict the occurrence of fracture basement and thus groundwater is contained within the fissure [17, 35]. The cluster bar chart of the overburden (Fig. 6b) shows the thick and thin overburden with ratio 1:1 (Fig. 6d). It was observed that the areas with thick overburden has fresh basement and area with thin overburden has fractured basement with ratio 2:1 (Fig. 6d) except VES 5 which a thin overburden and fresh basement. These zones do not satisfy the condition for obtaining a good and profitable groundwater quality. As reported by [36] that 20 m and 30 m should be the value recommended for overburden thickness to obtain a productive well. [32] and [37] also specify that lowest range of overburden thickness of 25 m should be adoptable for achievable groundwater exploit. To ensure great value and lasting results, [34] recommended that borehole should be situated where it can infiltrate highest inevitable thickness of the regolith. In regards to this, suitable and sufficient storativity and transmissivity is assured because the greater depth exploitability produced increase in well yield. In a typical basement complex terrain, basement fractures highly contribute significantly to groundwater yield. [15] and [39] reported that fractures influence the groundwater production too weathered layer possibility because of its reliable and dependable permeability. Fractured Bedrock with resistivity less than 750 Ωm is suggestive and ominous of highly fracture and permeable zones as result from weathering pattern with high aquiferous potential.

4. Conclusion

The research has been able to illuminate and place emphases on the significant of 2D geoelectrical and Statistical approach in subsurface structural mapping for groundwater investigation. Groundwater potential in basement complex terrain are established by a complex inter-relationship between the subsurface formations such as the groundwater flow pattern; weathering processes and depth; recharge and discharge processes; nature of the weathered layer; geology and post emplacement tectonic history. The study however uncovers that the variation of the geoelectric subsurface layers greatly affect the prospect of groundwater development and therefore, impact it significant in hydrogeological study especially when a borehole is about to be sited. This will enable the groundwater engineers to know the exact location(s) where the boreholes should be places so as to avoid excessive time wasting and other related future disaster which may arise from siting the borehole in wrong areas. In addition, the research has reveal that the study area is not favourably satisfied the condition and requirement for groundwater prospect due to the fact that the fresh basement is mostly beneath thick overburden and the fracture/weathered basement is mostly beneath the thin overburden. It is however recommended that if a sustainable and quality borehole is envisaged to be sited, the VES station above the fractured basement should be drilled to about 20 to 35 m. Thus profitable and quality groundwater supply will be extracted.

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